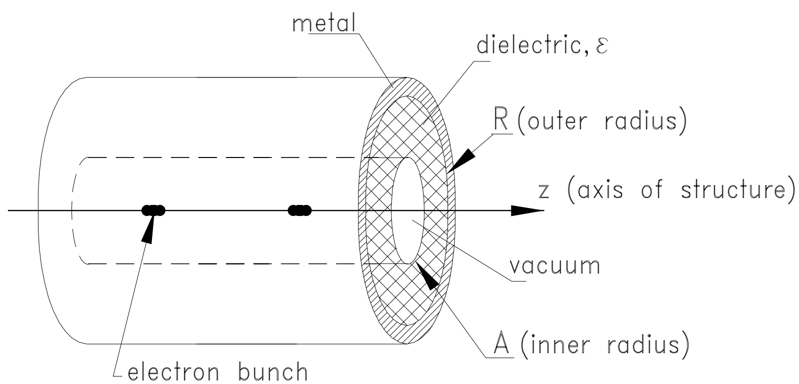
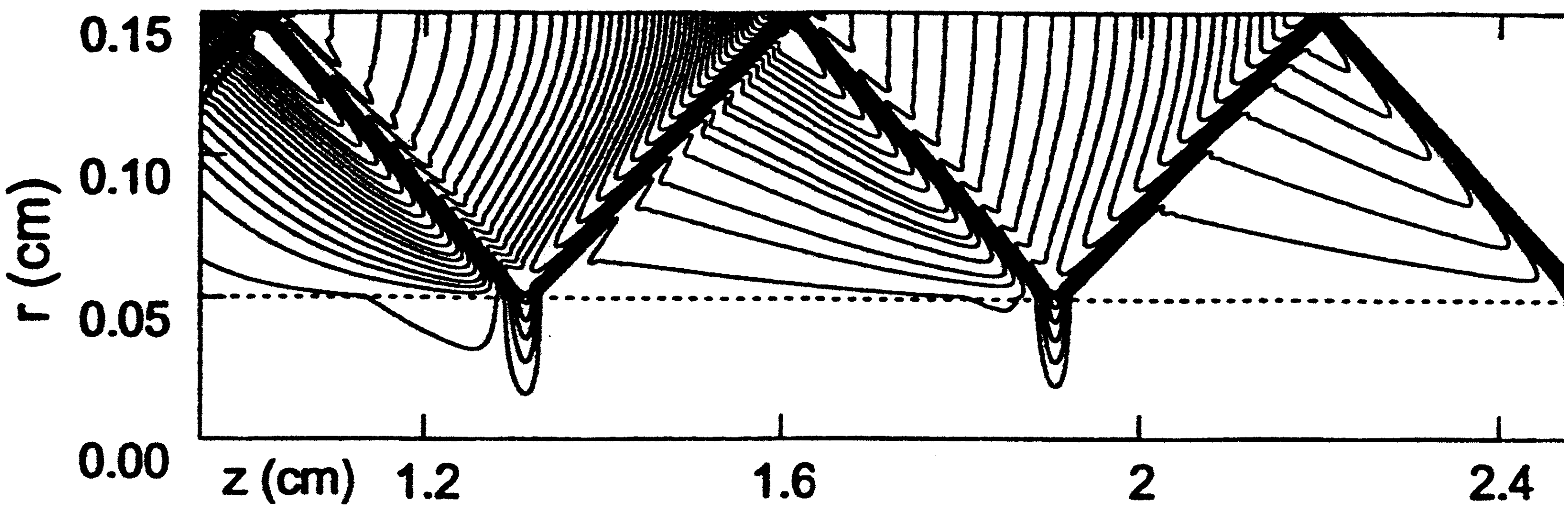
DWA: Dielectric Wakefield Acceleration

STUDIES OF WAKE FIELDS SET UP BY RELATIVISTIC ELECTRON BUNCHES IN A CYLINDRICAL DIELECTRIC-LINED WAVEGUIDE AND APPLICATION TO ACCELERATOR PHYSICS

- Portion of the Doctoral thesis project for Sergey V. Shchelkunov,
- Project advisor: Thomas C. Marshall





The wake field has a near-periodic pattern; E-lines of the radiation field is shown [ref:*"Theory of Wake fields in a Dielectric- Lined Waveguide", by S.Y. Park and J.L. Hirshfield, Phys. Rev. E 62, 1266- 1283, (2000)*]

Project Topics:

1) experimental demonstration of constructive superposition of wake-fields set up by consecutive drive bunches, which is the mechanism that creates high acceleration fields in DWAs

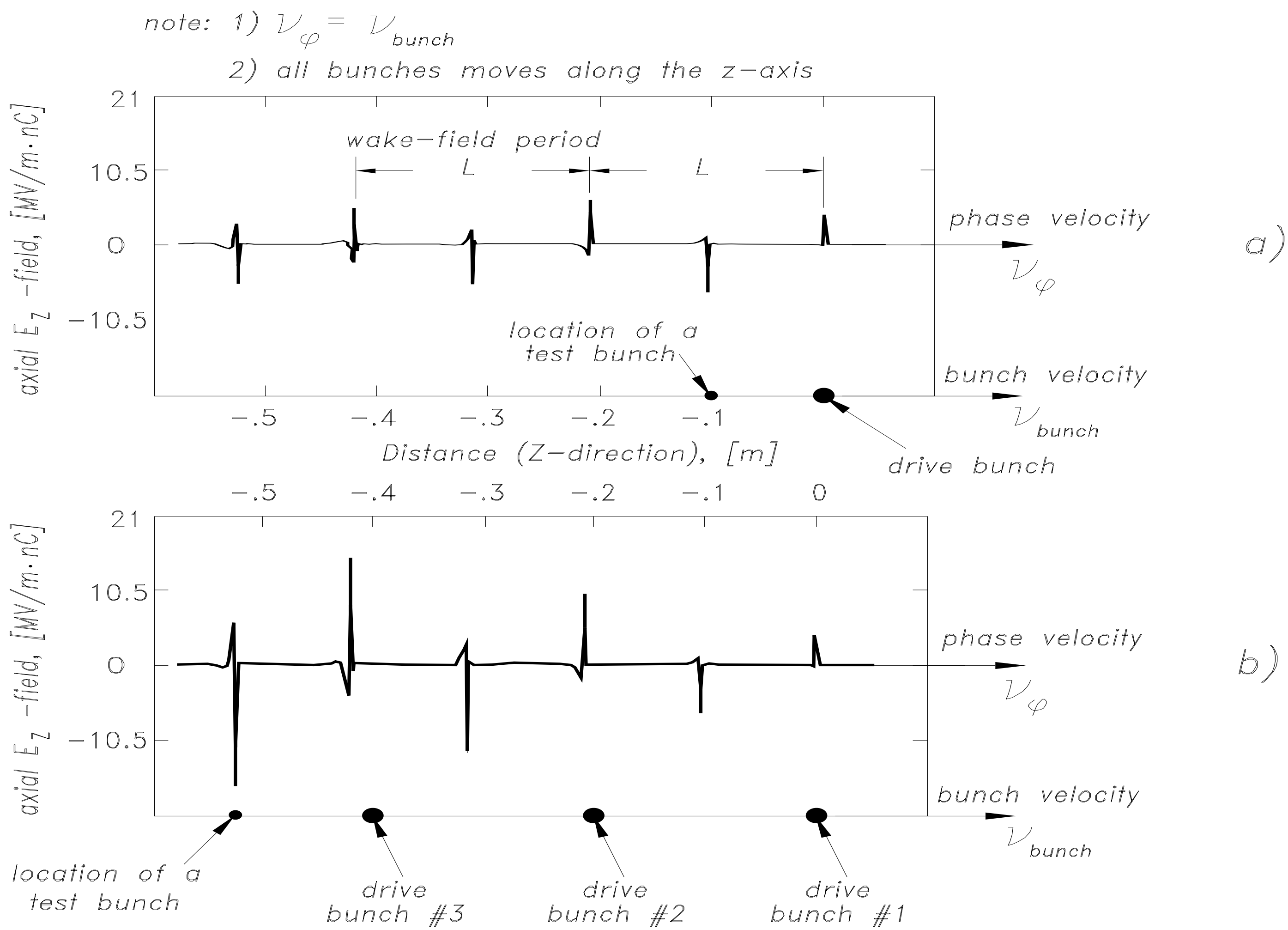
   *) S.V. Shchelkunov, T. C. Marshall, M.A. Babzien, J.L. Hirshfield, and M.A. LaPointe, PAC 2005 Conf. Proc. TPAE063
   **) Phys. Rev. ST Accel. Beams, with reviewers

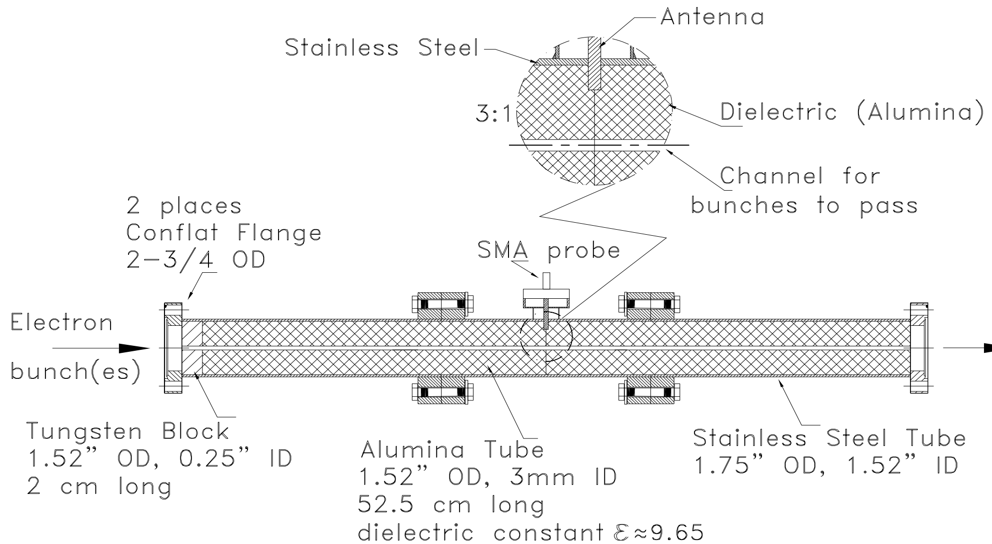
2) development of a nondestructive technique to measure bunch RMS-length in the psec range and below (~200fsec), by measuring the high- frequency spectrum of wake field radiation

   *) S.V. Shchelkunov, T. C. Marshall, J.L. Hirshfield, and M.A. LaPointe, AIP Conf. Proc. 737, 421 (2004), edited by V. Yakimenko
   **) Phys. Rev. ST Accel. Beams 8, 062801 (2005)

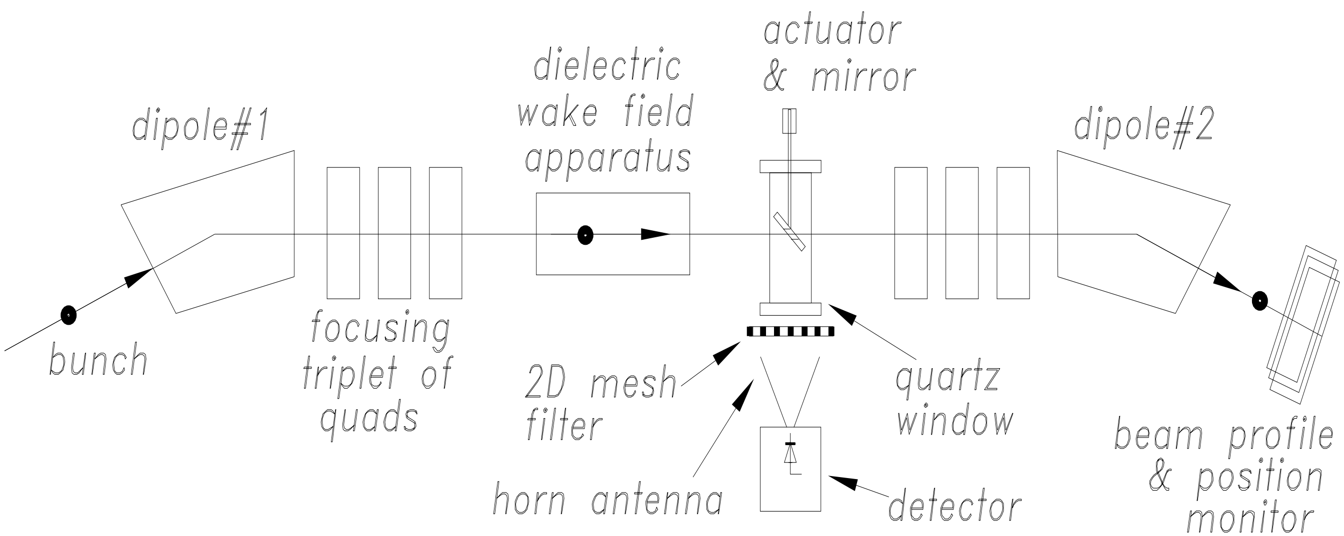
3) quantitative behavior of the dielectric wake field accelerator performance vs. the parameters

superposition of wake-fields set up by consecutive drive bunches

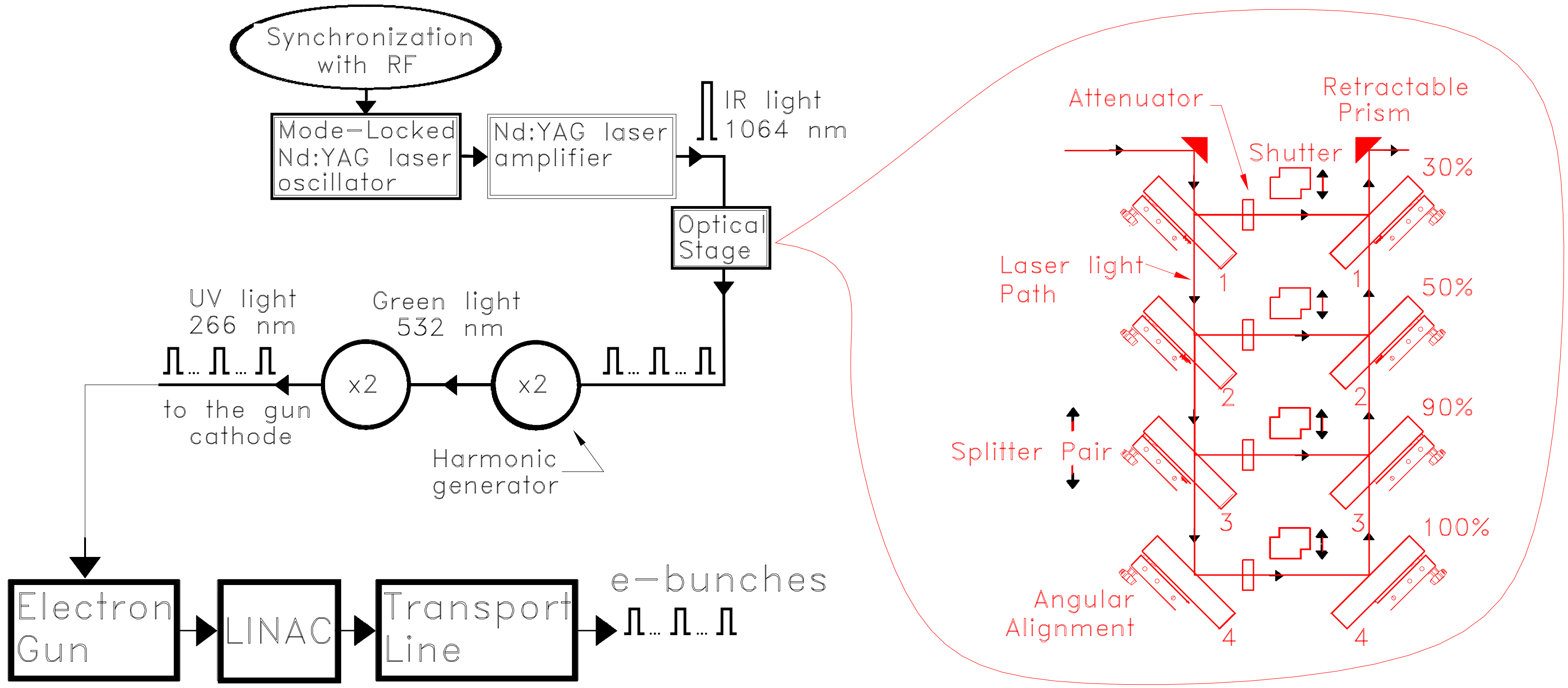




Dielectric Wake Field Apparatus (DWA) used for this experiment

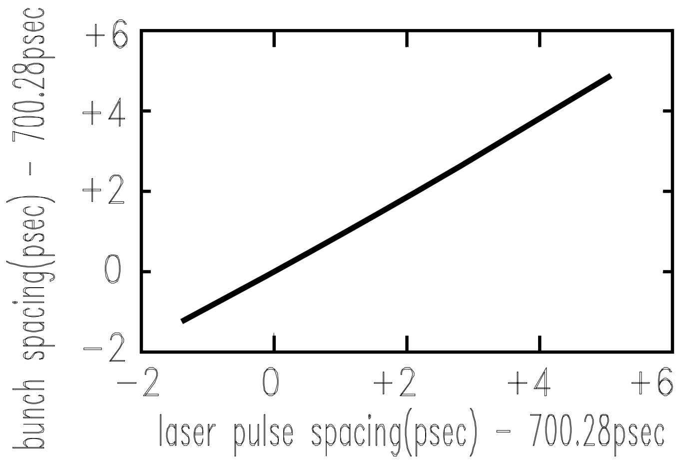


Schematic of experiment



?: Is the bunch spacing the same as the laser pulse spacing

A: No



a) first case

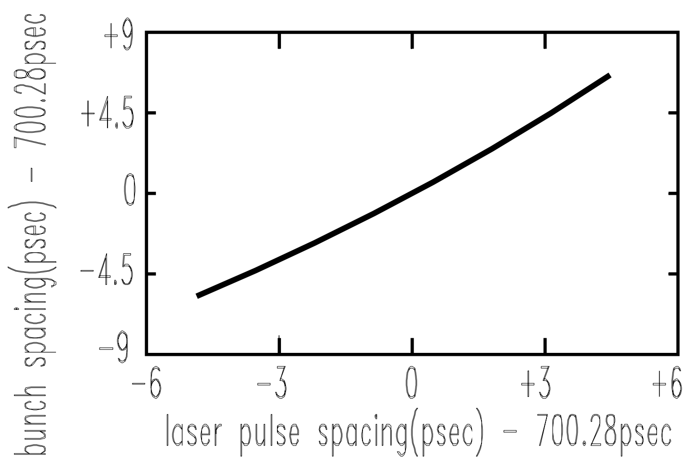
$\varphi_{gun} \sim 59.4^0$

$\varphi_{linac} \sim -17.9^0$

$E_{gun} \sim 100MV/m$

$E_{linac} \sim 7.6MV/m$

increment in bunch spacing
≈
increment in laser spacing



b) second case

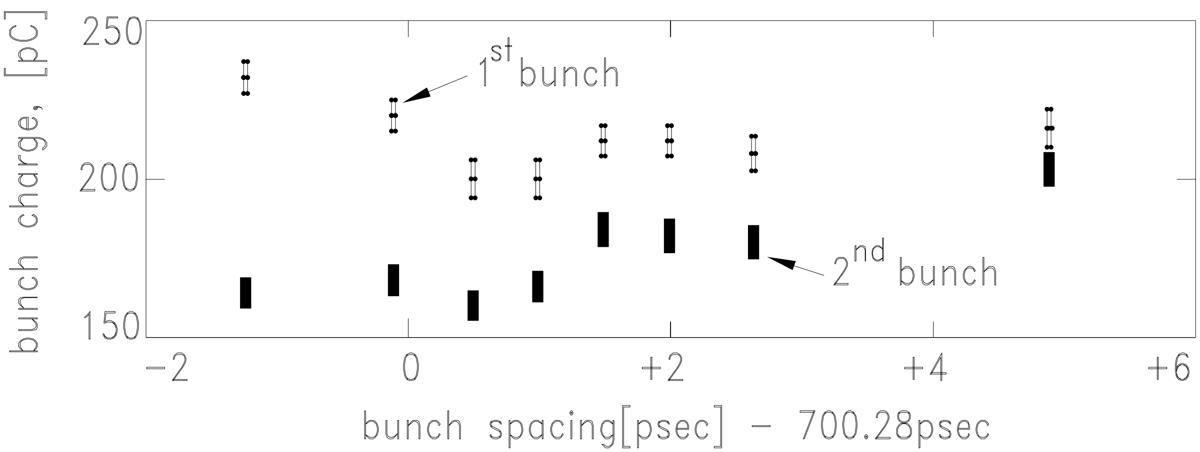
$\varphi_{gun} \sim 57^0$

$\varphi_{linac} \sim -88.5^0$

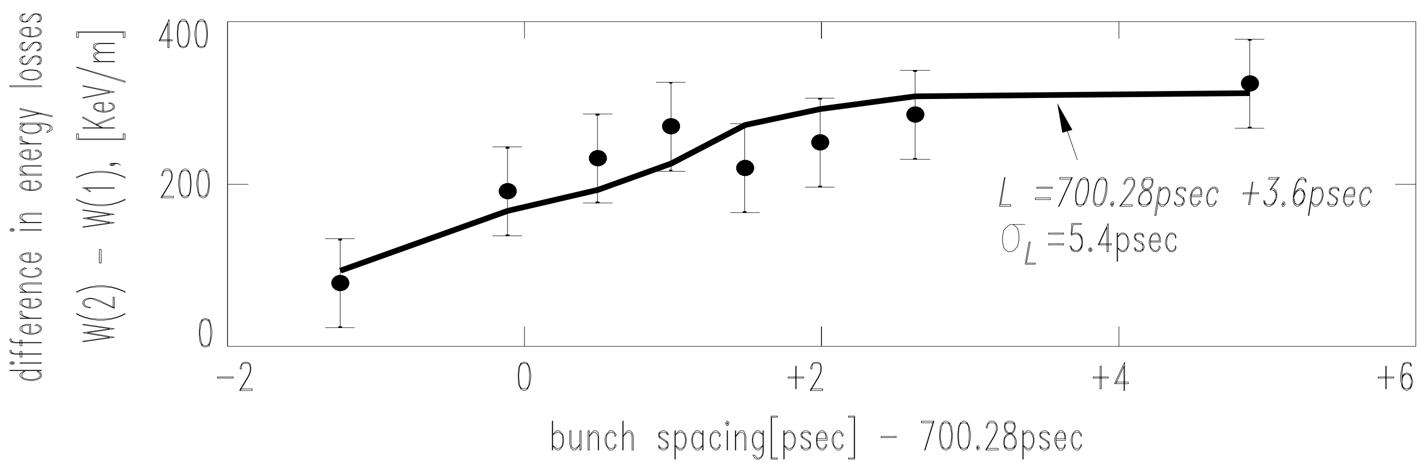
$E_{gun} \sim 51MV/m$

$E_{linac} \sim 7.94MV/m$

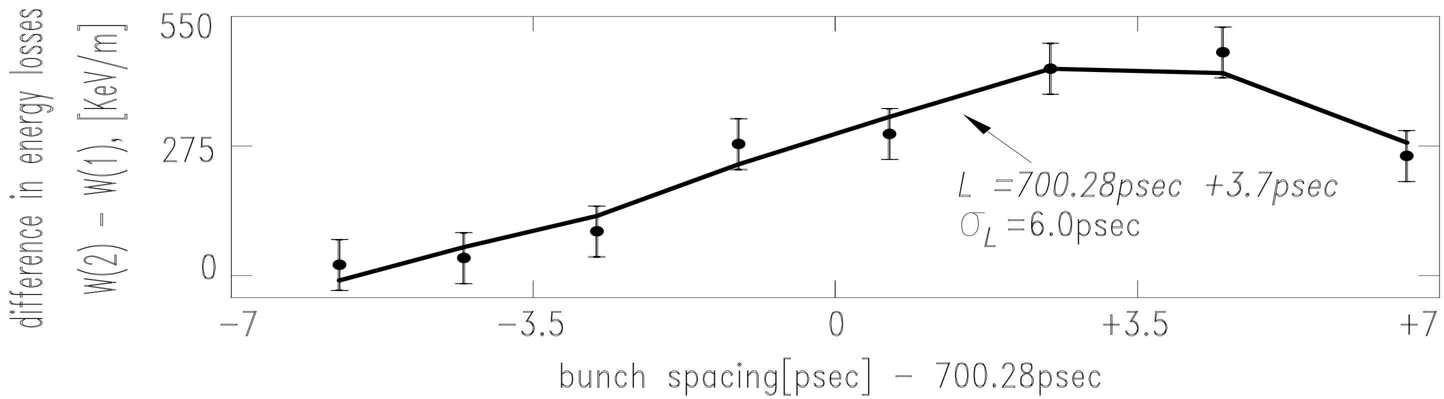
increment in bunch spacing
≈
1.5× increment in laser spacing



Charges of the 2nd and 1st bunches (the accuracy ≈ ±3%).



Measured difference in energy losses *W*(2) – *W*(1), vs. the bunch spacing. RMS-length = 5.4 ± 0.2psec. The solid line represents the best theoretical fit if *L* = 700.28psec + 3.6psec (or, equivalently, *L* = 20.994cm + 1080μm).



Measured difference in energy losses $W(2) - W(1)$, vs. the bunch spacing. RMS-length σ_L = 6.0 ± 0.43psec. The solid line represents the best theoretical fit if L = 700.28psec+ 3.7psec (or, equivalently, L = 20.994cm + 1110μm).

From the frequency measurement [J-M. Fang],
L = 700.28psec + ΔL = 700.28psec+4.08psec (ΔL – accuracy = ±10%)

Our observational technique has two important advantages:

a) the wake field period can be established with excellent accuracy;

b) agreement between theory and experiment can be verified when the bunch spacing is different from the wake field period (i.e. $S_{bunch} \neq L$)

Experimental evidence of constructive superposition

1. Argonne Group

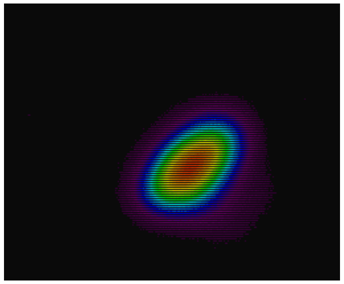
"Measurement Of the Longitudinal Wakefields In a Multimode, Delectric Wakefield Accelerator Driven By a Train Of Electron Bunches', by J.G. Power, M.E. Conde, W.Gai, R. Konecny, and P. Schoessow, Phys. Rev. ST Accel. Beams 3, 101302, (2000)

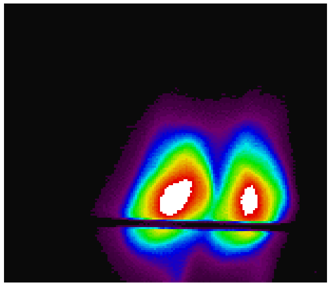
2. Our Group

"Experimental Observation of Constructive Superposition of Wake Fields Generated by Electron Bunches in a Dielectric-Lined Waveguide", by S.V. Shchelkunov, T.C. Marshall, J.L. Hirshfield, M.A. Babzien, and M.A. LaPointe, (in review with PRST)

	ε	inner radius, [*mm*]	bunch RMS-length, [*psec*]/[*mm*]	Number of excited eigenmodes	Wake-field full footprint, [*psec*]/[*mm*]	Peak Accel. Field after one bunch [$MV/m \cdot nC$]
Argonne	38.1[a]	5	30 /9	~10	74 / 22	0.09
Our	9.65[b]	1.5	6 /1.8	~40	13.5 / 4	2.65

a) material $CaTiO_3$ – $LaAlO_3$; b) material Al_2O_3





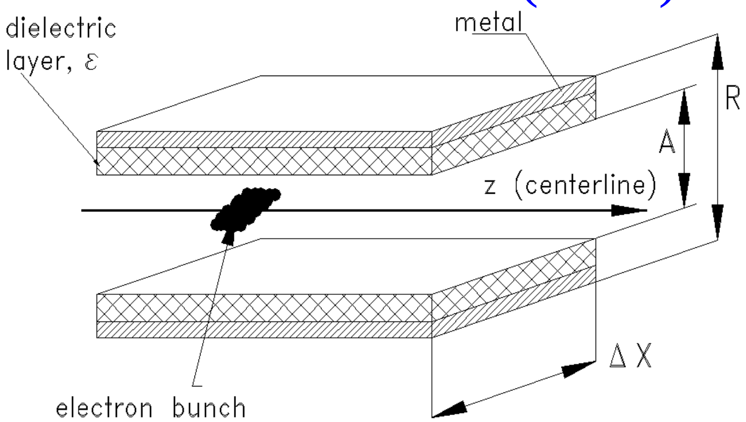
$$\Delta X, \Delta Y = D_{X,Y} \cdot \frac{W_2 - W_1}{W_1}$$

where $W_2 - W_1$ happens every time when

the bunch spacing $\neq$ RF period $\times$ N

Tunable structure (users) + ATF laser upgrade

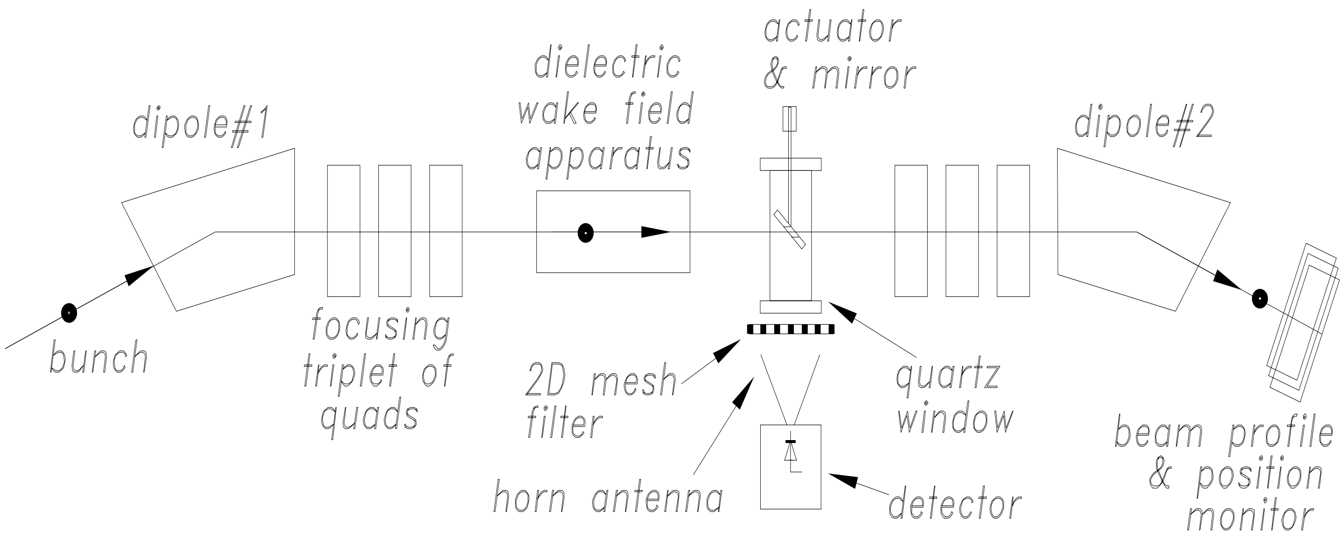
(2-3) bunches $\rightarrow$ 10-15 bunches

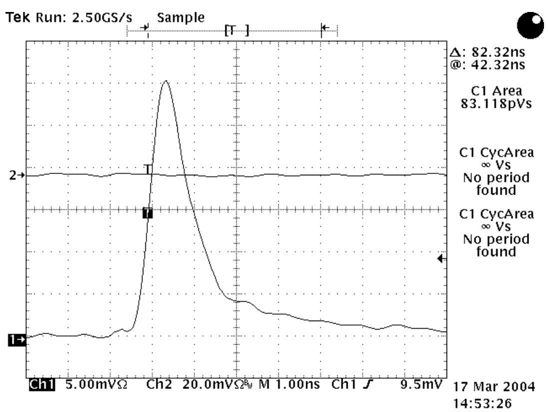


Truly multi bunch experiment

Non-destructive diagnostic for short bunches

*) AIP Conf. Proc. 737, 421 (2004) **) Phys. Rev. ST Accel. Beams 8, 062801 (2005)

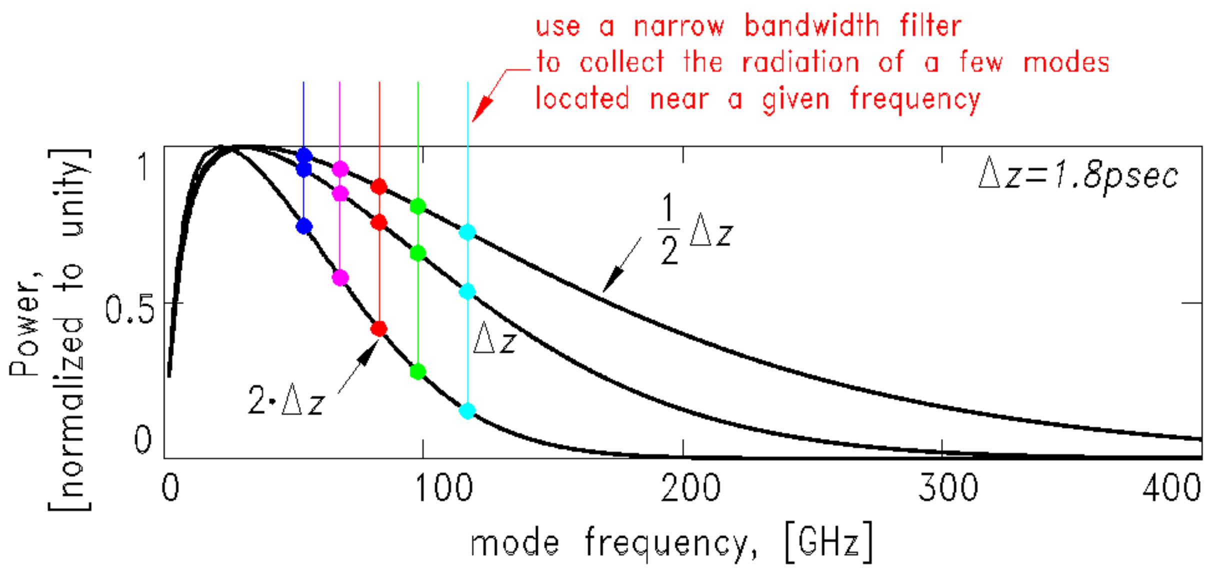




MM-wave detector signal
(divisions: 5 mV × 1 nsec)

for a bunch distributed along a RMS-length

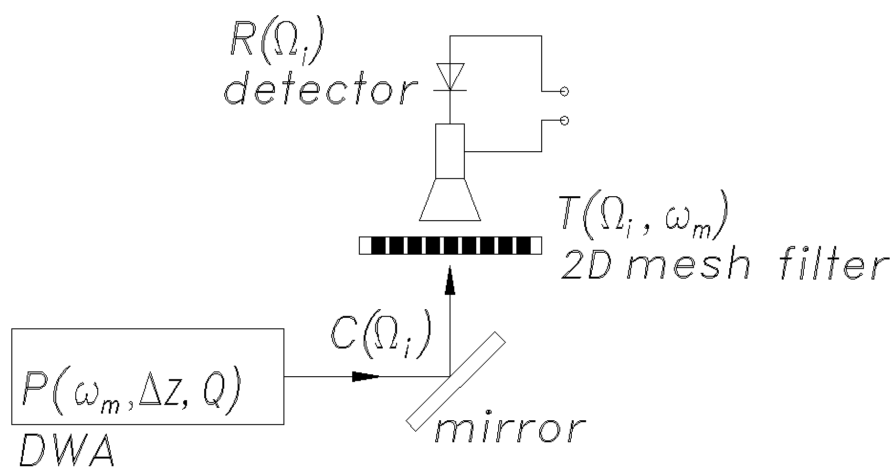
$$\Delta z = 2\sqrt{\langle z^2\rangle - \langle z\rangle^2}$$

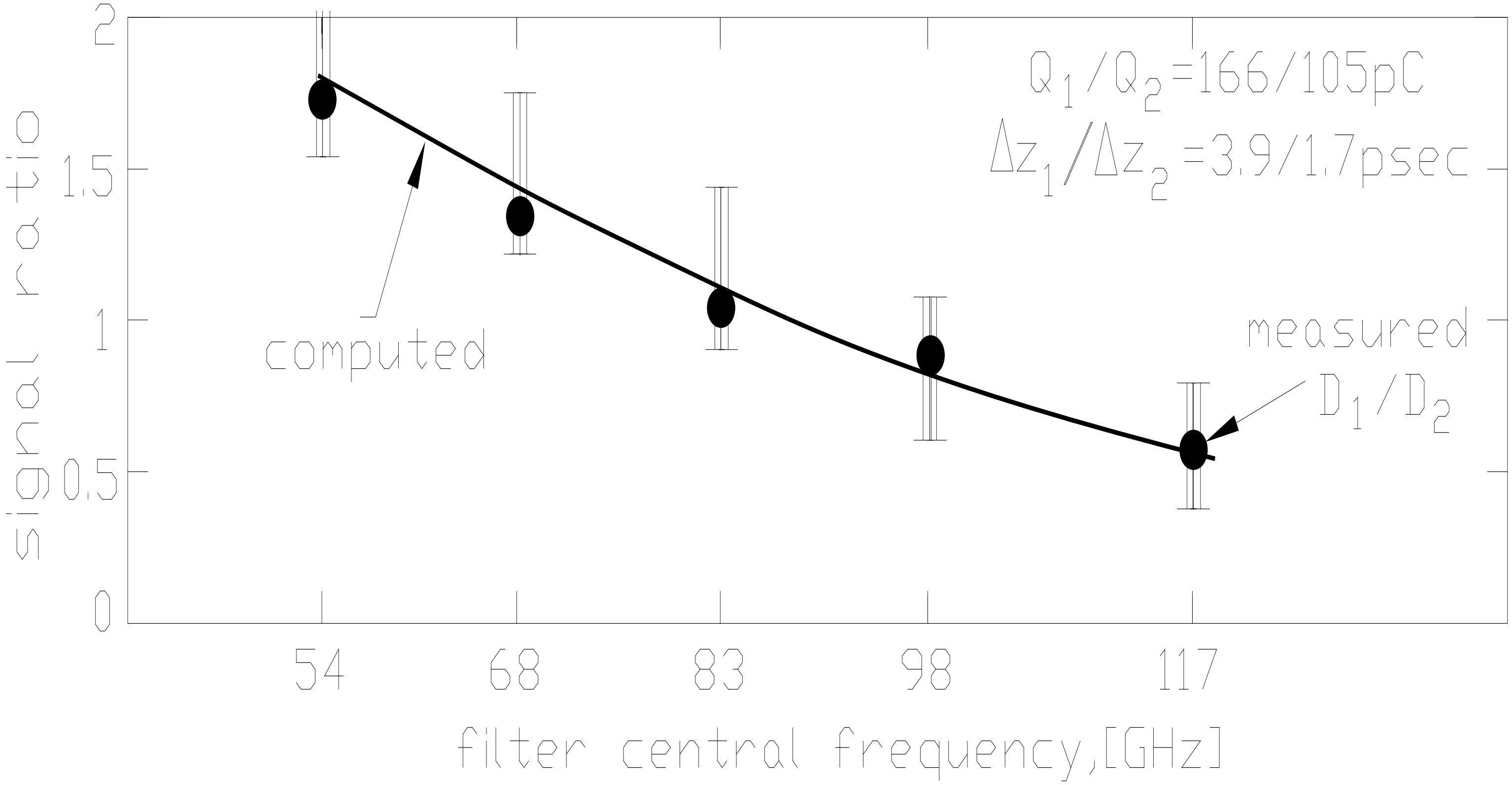


one bunch: Δz_1 , Q_1

another : Δz_2 , Q_2

$$\frac{\sum_{m=m1}^{m2} T(\Omega_i,\omega_m)P(\omega_m,\Delta z_1,Q_1)}{\sum_{m=m1}^{m2} T(\Omega_i,\omega_m)P(\omega_m,\Delta z_2,Q_2)} = \frac{D_{i,1}}{D_{i,2}}$$





2
1.5
1
0.5
0
signal ratio
54
68
83
98
117
filter central frequency,[GHz]
Q1/Q2=166/105pC
Δz1/Δz2=3.9/1.7psec
computed
measured
D1/D2

FEATURES of METHOD

1)• Nondestructive TECHNIQUE

2)• Is not sensitive to the bunch longitudinal and radial distribution

3)• Allows finding the RMS- length and charge

4)• The accuracy $\delta\Delta z / \Delta z$ of measurement $\delta\Delta z / \Delta z = \left(C_{\Delta z} / \Delta z^2\right) \cdot \left(\Delta D / 2\overline{D}\right)$

5)• The minimum RMS length one can resolve $\Delta z_{MIN} = \sqrt{C_{\Delta z} \cdot \left(\Delta D / 2\overline{D}\right)}$

$\Delta D/2D \approx 1.5\%$

with filtering to 120 GHz $C_{\Delta Z} = 13.8$ psec^2

$\delta\Delta z / \Delta z = \delta\Delta z /$ 3psec $\approx 2\%$

$\Delta z_{MIN} \approx 1/2$ psec

with filtering to 300 GHz $C_{\Delta Z} = 2.4$ psec^2

$\delta\Delta z / \Delta z = \delta\Delta z /$ 3psec $\approx 0.4\%$

$\Delta z_{MIN} \approx$ 190 fsec

6) • spectrum of many bunches $\rightarrow$ with odd number (3) spaced by L, spectrum resembles that of a single bunch

Superposition of Wake Field + Radiation Spectrum Measurement

=

Correct understanding of interaction between wake fields and electron bunches →

Tool to predict behavior and
design Dielectric Wake Field Accelerator
(accelerating gradient, efficiency, energy spread
vs. parameters)

Problems to solve
Electric threshold + Tuning the Wake Field Period